Design of Pneumatic Conveying System

Akhil Raj P  
UG Student  
Department of Mechanical Engineering  
Saintgits College of Engineering, Kottayam-686532, Kerala, India

Anish Joseph  
UG Student  
Department of Mechanical Engineering  
Saintgits College of Engineering, Kottayam-686532, Kerala, India

Harinarayanan S  
UG Student  
Department of Mechanical Engineering  
Saintgits College of Engineering, Kottayam-686532, Kerala, India

Er. Tobin Thomas  
Assistant Professor  
Department of Mechanical Engineering  
Saintgits College of Engineering, Kottayam-686532, Kerala, India

Abstract

Conveying of powder like substance in industries are used by conventional conveyors such as bucket elevators, screw conveyors. In case of volatile or expensive materials such as Titanium dioxide, which is used mainly in paint industries, usage of conventional conveyors is not economical. Titanium dioxide powder is used for the production of inks, plastics, textiles, ceramics etc. It is commonly produced by the chloride route process of Rutile grade pigment. Due to the fine powdering nature of the material this system has certain problems like frequent spillage and fine powder escaping. Though some amount of powder is regained with the help of filtrate recovery process, this process is time consuming and expensive. Thus this spillage and other associated troubles are found to be one of the serious problems faced by the industries. Here fully refined powder material is wasted whereby the industries suffer huge losses both directly and indirectly. Hence this study is to determine the reasons behind this problem and to suggest a suitable remedy. As a long term solution, replacement of the conventional conveying system with a Pneumatic conveying system was suggested.

Keywords: Titanium dioxide powder, screw conveyers, bucket elevator, pneumatic conveying system

I. INTRODUCTION

Pneumatic conveying systems are basically quite simple and are eminentily suitable for the transport of powdered and granular materials in factory, site and plant situations. The system requirements are a source of compressed gas, usually air, a feed device, a conveying pipeline and a receiver to disengage the conveyed material and carrier gas.

The system is totally enclosed, and if it is required, the system can operate entirely without moving parts coming into contact with the conveyed material. High, low or negative pressures can be used to convey materials. For hygroscopic materials dry air can be used, and for potentially explosive materials an inert gas such as nitrogen can be employed. A particular advantage is that materials can be fed into reception vessels maintained at a high pressure if required.

Pipelines can run horizontally, as well as vertically up and down, and with bends in the pipeline any combination of orientations can be accommodated in a single pipeline run. Conveying materials vertically up or vertically down presents no more of a problem than conveying horizontally. Material flow rates can be controlled easily and monitored to continuously check input and output, and most systems can be arranged for completely automatic operation.

Pneumatic conveying systems are particularly versatile. A very wide range of materials can be handled and they are totally enclosed by the system and pipeline. This means that potentially hazardous materials can be conveyed quite safely. There is minimal risk of dust generation and so these systems generally meet the requirements of any local Health and Safety Legislation with little or no difficulty.

II. MODE OF CONVEYING

For continuous conveying and batch conveying if the batch size is large, two modes of conveying are recognized. If the material is conveyed in suspension in the air through the pipeline it is referred to as dilute phase conveying. If the material is conveyed at low velocity in a non-suspension mode, through all or part of the pipeline, it is referred to as dense phase conveying.

A. Dilute phase

Almost any material can be conveyed in dilute phase, suspension flow through a pipeline, regardless of the particle size, shape or density. It is often referred to as suspension flow because the particles are held in suspension in the air as they are blown or sucked through the pipeline. A relatively high velocity is required and so power requirements can also be high but there is virtually no limit to the range of materials that can be conveyed.
There will be contact between the conveyed material and the pipeline, and particularly the bends, and so due consideration must be given to the conveying of both friable and abrasive materials. With very small particles there will be few impacts but with large particles gravitational force plays a part and they will tend to ‘skip’ along horizontal pipelines.

Many materials are naturally capable of being conveyed in dense phase flow at low velocity. These materials can also be conveyed in dilute phase if required. If a high velocity is used to convey any material such that it is conveyed in suspension in the air, then it is conveyed in dilute phase.

III. REQUIREMENT OF PNEUMATIC CONVEYING SYSTEM

In a typical pneumatic conveying system there are different components for feeding the material, transporting the material and also for discharging. The new design will have the following components.

- Drive system
- Air movers
- Pipeline sections
- Material feeding system

In addition to the above mentioned devices, usually an air-dryer is also installed just after the air mover unit. This is done to ensure that the air discharged from the air mover system has the required specific humidity and the required moisture content. For the effective conveying of solid the air must have minimum moisture content this is achieved by using an air cooling system after the air mover. The cooling of air will make the conveying air homogeneous that is any foreign particle (oil or dirt content) from the air mover lubricant is condensed due to the cooling. Usually coils of water at lower temperature than the atmosphere is used for this purpose. The range of temperature of the discharged air is 15°C-30°C.

IV. SYSTEM DESIGN

In order to design the pneumatic conveying system the criteria for designing must be regarding the requirements mentioned in the previous chapter such as

- Design of pipeline diameter, length and the material of the pipe.
- Head loss produced inside the pipeline due to friction and bend section.
- Selection of Air mover system, drive system, material feeding system and air drying system.

All of the above criteria is designed and selected by using the standard design calculations from the ‘Pneumatic conveying system design guide’ by David Mills. Thus for design calculations mainly two aspects about pneumatic conveying are used and they are.

A. Mode of conveying

For designing the new pneumatic system layout the primary factor to look into is the mode of conveying or mode of operation. Since the system that is most suitable for conveying powder like particle is Closed loop system, the most ideal mode for conveying is Dilute phase conveying. For dilute phase conveying the important variable to note is the ‘solid loading ratio’.

1) Mode of conveying.
2) Conveying capacity.
3) Conveying pressure
B. Solid loading ratio (\( \phi \))

Solids loading ratio or phase density, is a useful parameter in helping to visualize the flow. It is the ratio of the mass flow rate of the material conveyed divided by the mass flow rate of the air used to convey the material. It is expressed in a dimensionless form.

For plug type flow the use of solids loading ratio is not as appropriate, for the numbers do not have the same significance. Since the materials have to be very permeable, air permeates readily through the plugs. Maximum values of solids loading ratio, therefore, are only of the order of about 30, even with high values of conveying line pressure drop. If a material is conveyed at a solids loading ratio of 10, for example, it could be conveyed in dilute phase or dense phase. It would only be with the value of the conveying line inlet air velocity that the mode of flow could be determined. But in the case of dilute phase conveying the preferred ratio of solid to air is 2:1.

C. Conveying capacity

For standard designing of pneumatic conveying design, conveying capacity is inversely proportional to conveying distance

\[
\text{Conveying capacity} \alpha \frac{1}{\text{Conveying distance}}
\]

D. Conveying pressure

In the case of conveying pressure the relation between pressure and distance of conveying is linear or proportional. That is if the distance to be conveyed is more the more pressure will be available for conveying. And thus affects the overall conveying capacity of the system.

Conveying pressure \( \alpha \) Conveying distance

V. DESIGN CALCULATIONS

For design calculations, values such as density, mass etc of Titanium Dioxide powder is used and also conveying length is incorporated with horizontal as well as vertical sections.

A. Design of the pipeline

To design the pipeline which conveys the TiO\(_2\) and air mixture from the starting point to the delivery point, let’s consider two sections of the pipe which is placed horizontally and vertically.

- Total length of pipeline = 35 meters
- Length of horizontal section = 20 meters

B. To find the diameter of the pipeline section

Density of TiO\(_2\) powder \( = 4320 \text{ Kg/m}^3 \)  
Density of air \( = 1.2 \text{ Kg/m}^3 \)

Required mass flow rate, \( \dot{m} = 8000 \text{ Kg/hr} \) (Theoretically)

Where actual discharge is 7000 Kg/hr but to ensure maximum performance, \( \dot{m} \) is taken as 8000 Kg/hr. Also the assumed velocity of air inside the pipe is 35 m/s.

From David Mills ‘Pneumatic conveying system design guide’ the solid loading ratio (\( \phi \)) is 0.5.

Therefore, \( \dot{m} = \rho \times A \times v = 8000 \text{ Kg/hr} = 2.2 \text{ Kg/s} \)

Were \( \rho \) is the density of the mixture, \( A \) is the area of cross-section of the pipe and \( v \) is the velocity of discharge. By considering the solid loading ratio \( \dot{m} \) becomes

\[
\phi = \frac{\dot{m} \text{ powder}}{3.6 \dot{m} \text{ air}}
\]

\[
\dot{m} = \phi \times \rho \times A \times v
\]

\[2.2 = 2 \times 1.2 \times \pi/4 \times D^2 \times 35 \]

Thus, \( D^2 = \frac{2.2 \times 4}{2(1.2 \times 35 \times \pi)} = 0.18343 \text{ m} \sim 7 \text{ inch} \)

C. Material of the pipe

Since the TiO\(_2\) powder is inert and non corrosive, MS (mild steel) seamless tube pipes are suggested for design.

D. Head losses inside the pipe

The frictional loss produced inside a pipe having length ‘l’, diameter ‘D’, velocity of flow ‘v’ and frictional coefficient ‘f’ is \( h_f = \frac{4fl^2}{2gD^2} \)

From Moody’s chart the frictional factor ‘4f’ is 0.04.

The conveying length is 20 m horizontal and 10 m vertical. So keeping in mind the scaling factor, the equivalent length is \( L = 30+20 = 50 \text{ m} \)

So frictional loss inside the pipe, \( h_f = \frac{0.04 \times 50 \times 35^2}{2 \times 9.81 \times 0.1834} = 680.87 \text{ m of TiO}_2 \)
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Bend losses in the pipe = Number of bends × 0.5 × \( \frac{v^2}{2g} \)

= 2 × 0.5 × 2 × \( \frac{35^2}{2 \times 9.81} \) = 62.43 m of TiO₂

Total head loss = 680.87 + 62.43 = 743.3 m of TiO₂

Equivalent head of air, \( h_{air} = \frac{\rho_{TiO_2} \times \text{total head loss}}{\rho_{air}} \)

= \( \frac{4320 \times 743.3}{1.2} \) = 26.7588 × 10⁵ m of air

E. Design of the blower

Air discharge through the blower = Cross-sectional area × Velocity of the air

Area of pipe = \( \pi/4 \times D^2 \) = \( \pi/4 \times 0.1834^2 \) = 0.0264 m²

Velocity of air = 35 m/s

Therefore discharge = 0.0264 × 35 = 0.924 m³/s

F. Power required

Power delivered at the output of the blower is the product of density of powder, volume rate of powder, acceleration due to gravity and total head of mixture.

Therefore power, \( P_{out} = \rho \times Q \times g \times H \)

Volume rate, \( Q = \frac{m}{\rho} = \frac{2.22}{4320} = 5.138 \times 10^{-4} \) m³/s

Thus, \( P_{out} = 4320 \times 5.138 \times 10^{-4} \times 9.81 \times 743.3 = 16.18 \) KW

Considering the factor of safety be 1.5 the design power becomes

\( P_{out} = 16.18 \times 1.5 = 24.27 \) KW

Power to be supplied at the input of the blower will be the ratio of the output power to the efficiency of the blower. To ensure optimum performance can be achieved by the blower we are selecting the blower efficiency to be 60%.

Input power, \( P_{in} = \frac{P_{out}}{\text{Blower efficiency}} \)

= \( \frac{24.27}{0.6} \) = 40.45 KW

In order to avoid any power variation due to the blower fluctuations, the rating of the motor is taken as 50 KW.

G. Velocity of powder

Mass flow rate, \( \dot{m} = 2.22 \) Kg/s (required)

Volume rate, \( Q = \frac{\dot{m}}{\rho} = \frac{2.22}{4320} = 5.138 \times 10^{-4} \) m³/s

Area of the pipe (cross-sectional), \( A = \pi/4 \times D^2 \)

= \( \pi/4 \times 0.1834^2 \) = 0.0264 m²

We know that discharge, \( Q = A \times v \)

Were ‘v’ is the velocity of powder. \( v = \frac{Q}{A} = \frac{5.138 \times 10^{-4}}{0.0264} = 0.0194 \) m/s

H. RPM of motor (N)

Velocity of air exiting the rotor of a motor, \( v = \frac{\pi \times D \times N}{60} \)

Were D is the diameter of the pipe and N is the RPM of the motor.

\( v = \frac{\pi \times 0.1834 \times N}{60} \)

Therefore, \( N = \frac{60 \times 35}{\pi \times 0.1834} \)

= 3644.76 rpm ~ 4000 rpm

VI. TECHNICAL SPECIFICATION

The technical details of the pneumatic system are listed in detail, which are based on the design calculations.

A. Conveying mixture

Density of TiO₂ powder = 4320 Kg/m³

Density of air = 1.2 Kg/m³
Mass flow rate = 2.22 Kg/sec
Velocity of air = 35 m/s
Volume flow rate = 5.138 ×10^4 m^3/s

**B. Process information**

Material to be handled = Titanium Di Oxide (TiO_2)
Material state = Powder state
Max. Lump size (Micron) = 0.15-0.5
Moisture content (% by Wt.) = 0.5-1.5 Normal (8 Max)
Temperature (° Celsius) = 125-150
Corrosive properties of materials = Non-Corrosive
Loose bulk density of material = 480 kg/m^3
Average capacity = 7T/hr.
Design capacity = 8T/hr.
Operational hours = 24 hrs
Contamination of material = Not Allowed
Type of powder feeding = Rotary Valve
Feeding system type = Pressure

**C. Conveying distance**

Total length (Metre) = 50
Vertical (Metre) = 20
No. of bends = 2
Conveying pipe (inches) = 7

**VII. NEW DESIGN LAYOUT**

The new design consists of the same units which are designed in the earlier phase. The following are the main components of the new design.
- Roots Air-Blower
- Air drying unit
- Rotary air lock
- Pipeline sections
- Bends
- Motors (exhaust and blower)
- Air injection system

The design layout shows the arrangements of pipelines from the roots blower and also to the exhaust system. There are two sets of bag filter and cyclone separators used in this system. This is to ensure the maximum collection of TiO_2. The layout also shows the two bends which is used in the design calculations. In addition to the design calculations, there are couple of additional units in the design layout such as ‘puff air’, ‘air filters’ and feeding bag.

Puff air is the air omitted out from the second bag filter to the atmosphere. This puff air will not contain any traces of TiO_2 powder in it. Air filters are provided from the first set of bag filter and the cyclone separator. This ensures that the air which is exhausted from the bag filter will be filtered before going into the blower. The presence of the air filter also ensure that no contaminants will enter the blower. Feeding bag is the collecting area of TiO_2 powder or the feeding bag can be said as a channel to the micronizer.

Air injection system are employed in the region of the first set of cyclone separators and bag filters. The air injection system bypasses the air discharged from the blower directly into the rotary air locks. This is done to avoid any chocking of TiO_2 powder inside the air lock because the material feeding takes place only due to the gravitational effect of the solid particles. Hence if the discharged air have a high velocity rate then the chance of blocking the air lock is more. Therefore this air injection system provides with a huge blow of air into the air locks avoiding any chocking.
VIII. CONCLUSION

The main objective of this project was to identify and eliminate the cause of spillage of finished powdered product. In order to reduce the spillage rate and to avoid loss of revenue a new system was proposed. So a new system was designed which is a long term solution for this. The proposed system replaces the existing conveying system to pneumatic conveying system.

Pneumatic conveying system is more advanced and effective mode of conveying. Since pneumatic systems are closed the chance of spillage is minimized. The benefit estimation and design layout is drawn along with design calculation of the overall system.

REFERENCES

[1] David Mills - Pneumatic conveying design guide 2004